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Optimizing Tomahawk Strikes

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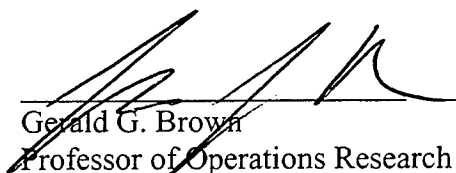
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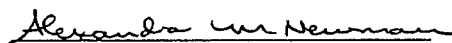
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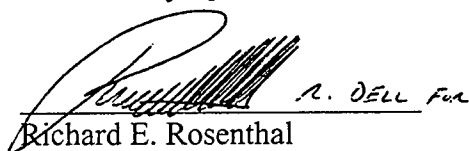
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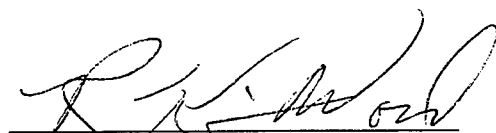

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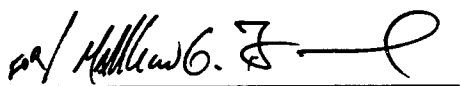

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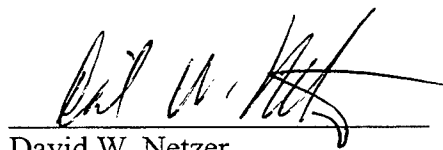

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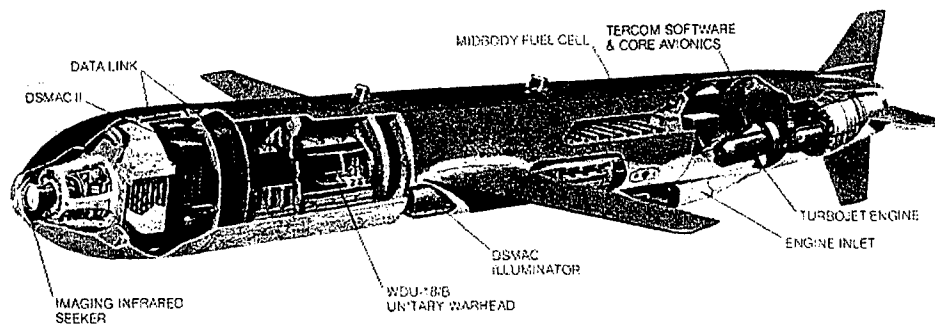
Optimizing Tomahawk Strikes

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The Tomahawk land attack missile (TLAM) is the Navy's weapon of choice for striking shore targets from the sea. A TLAM launched from a surface combatant or a submarine is a reliable, unmanned, long-range, accurate weapon with sufficient payload to threaten almost any shore target. The Operations Research Department at the Naval Postgraduate School has developed optimization-based decision support tools to optimize TLAM strikes from single firing units or entire battle groups. The idea is to execute each strike efficiently while retaining residual firepower, and while considering a number of other essential details. By applying mathematical modeling, the result is the ability to plan fleet and theater-wide strikes in seconds.

When the U.S. National Command Authority authorizes a Tomahawk land attack missile (TLAM) strike, its aim points pass down through the chain of command via a regional Commander-in-Chief and thence to the Battle Group Tomahawk Strike Coordinator (TSC). The TSC predesignates these aim points to firing platforms. Predesignation considers geographic proximity of candidate platforms to aim points, the inventory and location of TLAMs aboard each platform, engineering limitations on the way in which and the rate at which a platform can prepare and fire particular missiles, flight route coordination among TLAMs, and other tactical concerns. The TSC must also take care to leave his combat units with maximal residual firepower after the strike, individually and as a battle group. Once a firing platform receives from the TSC its designated aim points and told what TLAMs to use, the actual selection of which particular TLAMs to fire may be adjusted by its Combat Information Center based on the last-minute status of the platform and its individual missiles.

Predesignation is a complicated decision problem, and an important one. TLAMs are expensive, about \$600,000 each. They come equipped with several variations in guidance, propulsion, and payload, and we anticipate new variations with even more options. Surface combatants deploy with a variety of TLAMs preloaded in canisters. A missile salvo can be prepared and fired only if the designated TLAMs are located in canister cells that do not interfere with one another during preparation for launch.



Tomahawk (BGM-109C) land attack cruise missile. Its turbojet propulsion can accurately deliver a 450 kg warhead more than 1,300 km. Guidance options include inertial, terrain contour match (TERCOM), digital scene matching area correlation (DSMAC), and global positioning satellite (GPS).

Predesignation considers more than just a particular salvo or mission at hand. We must keep track of where candidate platforms are, what they are doing, and when they are scheduled to leave the theater of operations. We want to preserve as much residual firepower—defined here as the remaining salvo size of each missile type—as possible on the combat platforms that will be remaining with the battle group in theater, avoid predesignations that interfere with other duties of the firing platforms, and expend TLAMs from platforms that will soon be departing the theater.

The TSC currently predesignates by hand. There are no Tactical Decision Aids, Naval Warfare Publications, or Tactical Memoranda to guide this complex decision.

Optimal decision making is the central theme of operations research. And, the Operations Research (OR) Department at the Naval Postgraduate School is always looking for important, fleet-relevant problems for which it can develop and apply appropriate solution technologies, and integrate these into officer-student education. OR has been supported by Naval Surface Warfare Center Dahlgren Division and the Office of Naval Research to develop an automated decision support tool to optimally predesignate TLAM strikes.

An automated tool must consider all the details governing the preparation and firing of every missile in every launcher on every platform. A significant part of the research effort has been devoted to capturing all the engineering details and merging these with Naval tactics.

Kuykendall [1998] breaks ground with the first comprehensive operations analysis of the TLAM predesignation problem. He states the problem and how the Navy addresses it manually, assesses the capabilities of TLAM missile variants, illustrates the physical

layout of TLAM launch cells, and expresses their engineering peculiarities. Kuykendall then proposes an optimization model to predesignate aim points to TLAMs to maximize residual firepower for either a battle group or a single platform.

In the best spirit of Operations Research, Kuykendall conjures examples to illustrate why this problem is non-trivial, and why using only common sense and thumb rules can lead to bad tactics.

Consider the following trivial attack plan requiring one missile of type "A" and one of type "B." The firing platform has its missiles stowed in rows. For engineering reasons, a missile salvo can include at most one missile from each row:

B A C B
C B A A

If we shoot "A" from the first row, and "B" from the second, the attack mission is satisfied.

However, we leave ourselves with insufficient residual firepower if the following mission calls for two "A's" or two "B's." On the other hand, had we chosen to shoot:

B A C B
C B A A

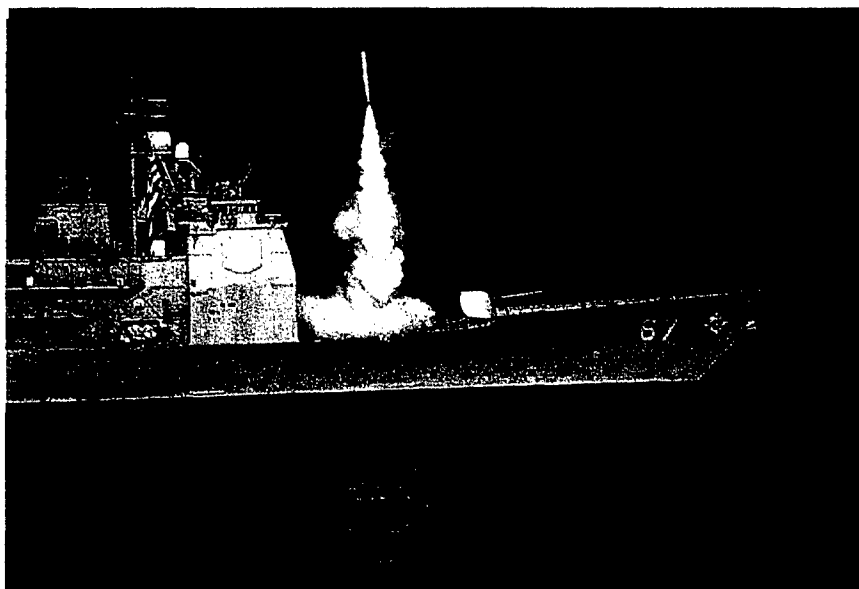
then we would have residual capability to fire any requested combination of two missiles in the next mission. You may have quickly seen the better salvo for this trivial example, but picture yourself having to solve the same problem with an attack plan calling for 100 predesignations to be chosen from 250 missiles on seven platforms, instead of these two predesignations from eight missiles on just one platform.

This trivial example is important for two reasons. First, Kuykendall shows the subtlety of the problem with elegant simplicity. Second, he points to what may have been a flaw in an early Navy attempt at automating missile predesignation. The first solution in the example typifies the inferiority of applying a simple rule of thumb, such as: Use the first "A" you find; then use the first "B."

- maximize residual firing capability.

Kirk develops a number of ambitious, extremely detailed mathematical optimization models. He tests them with scenarios provided by the research sponsor. Kirk's solutions and analysis establish that the essence of Tomahawk strike planning has been captured, and that the strike plans can be optimized. Kirk's objectives can be reordered, redefined, prioritized, or softened with the use of aspiration levels that seek most of the optimal value of each function, but not all of it, thus providing more flexibility for lower-level considerations.

Hodge [1999] develops a prioritized target list that he uses to mimic the optimal decisions of Kirk's most comprehensive model with a fast heuristic algorithm that selects firing platforms, and then predesignated targets from the list in a single pass. When the target ordering priorities are well stated for the scenario at hand, this one-pass heuristic suggests good strike plans very quickly. To prove this, Hodge uses Kirk's much slower, but optimal, results for qualitative assessment. Hodge's heuristic takes less than a minute to deliver strike plans good enough for operational use.



Flying her battle flag, USS Shiloh (CG-67) fires a Tomahawk land attack missile in Operation Desert Strike, 3 September 1996.

Arnold [2000] improves Hodge's strike plans, and adds assurance that a recommended strike plan cannot be improved by any simple adjustment. This is key to retaining the hard-earned confidence of planners who might otherwise lose faith if some

minor blemish were to be discovered in a near-optimal heuristic solution. Arnold also accommodates:

- submarine launch platforms with their unique capabilities,
- the restriction of individual aim point assignments to a single firing platform to minimize collateral damage,
- the assignment of special types of redundant predesignations, and
- manual prioritization of the targets.

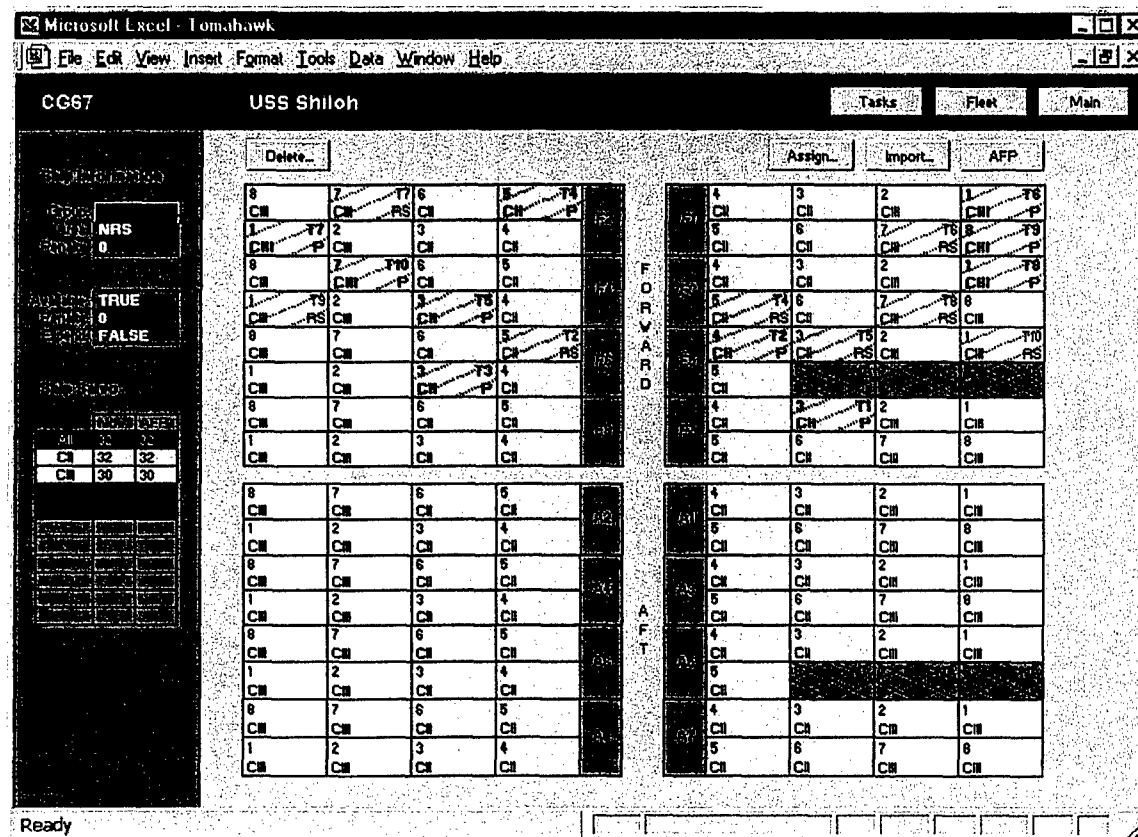
For a scenario with 104 targets and seven firing platforms, the Arnold heuristic delivers a complete strike plan in less than ten seconds. Equally important, we can forecast the necessary computation time for Arnold's heuristic. This is key for real-time decision support.

Kubu [2001] suggests modifications (e.g., shifting the launch time of a missile) in the event that a predesignation cannot be made. These modifications can help the TSC arrive at a list of targets and their associated attributes such that under heavy strikes, most of the intended targets can be struck with minimal alterations to the original plan. The modifications would be proposed if and when an initial application of the heuristic deems certain missile-to-target predesignations infeasible based on missile inventories, the number and type of missiles required for the strike, and target attributes (e.g., the launch time for a missile to ensure on-time arrival at the target).

Wingert [2001] is comparing our automated strike planner with actual Fleet exercise decisions. The idea is to reconcile our results with those of experienced decision makers to make sure that the automated tool captures subtle human reasoning that may have been overlooked. He is also developing an interactive mode by which the TSC can manually control all or part of the heuristic, while continually receiving guidance from the heuristic on the influence his changes have on overall strike efficiency. This enhances the credibility of an automatic tool that, by its nature, should be received skeptically: There will be extenuating circumstances that cannot be anticipated and incorporated in advance.

We have developed a graphical user interface to maintain and display the state of every combatant, every launcher, and every missile. The interface has drill-down and fly-over features to permit arbitrary navigation among all the data elements and displays: This is important, because the TSC needs a global view of his battle group. It is vital to try to display not only which TLAM to fire from which platform and position, but visible

reckoning of why. We also display aggregate statistics that measure the state of battle group firepower as a consequence of any action taken. This graphical user interface is the vehicle Wingcart's manual method will use to directly accept guidance from the TSC.



User Interface View of USS Shilo (CG-67) Tomahawk Status. This screen highlights with cross hatching the predesignation of a salvo of Tomahawk missiles. Primary assignments are displayed in bold. Redundant designations—used in case a primary fails—are shown in standard font. Codes shown in each cell indicate the assigned task number (T1,T2,...), primary or redundant (P, RS) and type of tomahawk missile (CII, CIII). The type of missile is also discernable by the color of the cell. The left-hand side of the screen shows summary information about the battle group and the Shilo's missile load before and after the designated missiles are fired. Each ship has such a display, and companion displays (not shown) detail tasking and other details. One button on this dashboard optimizes an entire fleet-wide Tomahawk strike.

Research on optimization of TLAM strikes continues with collaboration among our faculty, a succession of surface naval officer graduate students, and fleet experts at Dahlgren. The faculty provide guidance and continuity, the students are highly motivated by their anticipation of actually using their tools when they get back to sea, and Dahlgren will ultimately test, approve, document, and issue a product to our fleet.

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